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Different characteristics of plasma meniscus formation between positive and negative beam extractions

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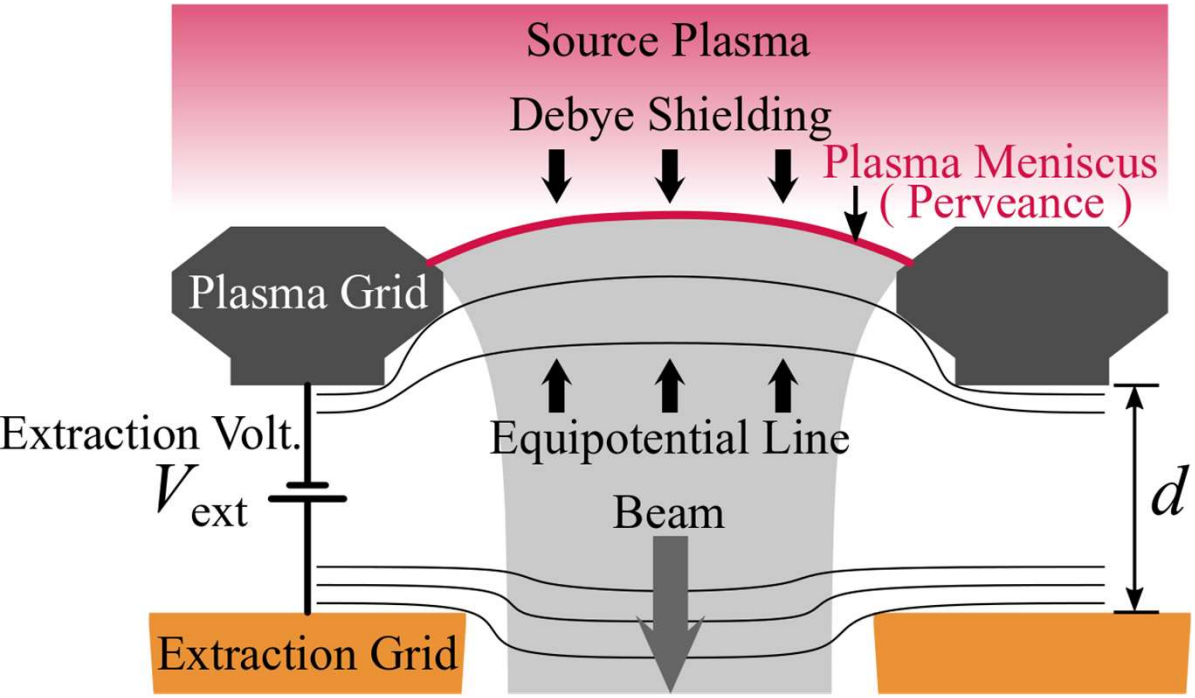
Plasma meniscus formation

Plasma meniscus is a boundary between source plasma and the beam and constructs electrostatic lens for charged particles, which plays a crucial role for beam focusing.



For positive ion extraction,

- Competition of penetration of electric field and Debye shielding
- Bohm criterion：$V = C_s$
- Perveance (Child-Langmuir law) is an index of electrostatic lens effect of meniscus

$$P = \frac{I_{\mathrm{beam}}}{V_{\mathrm{ext}}^{1.5}}$$

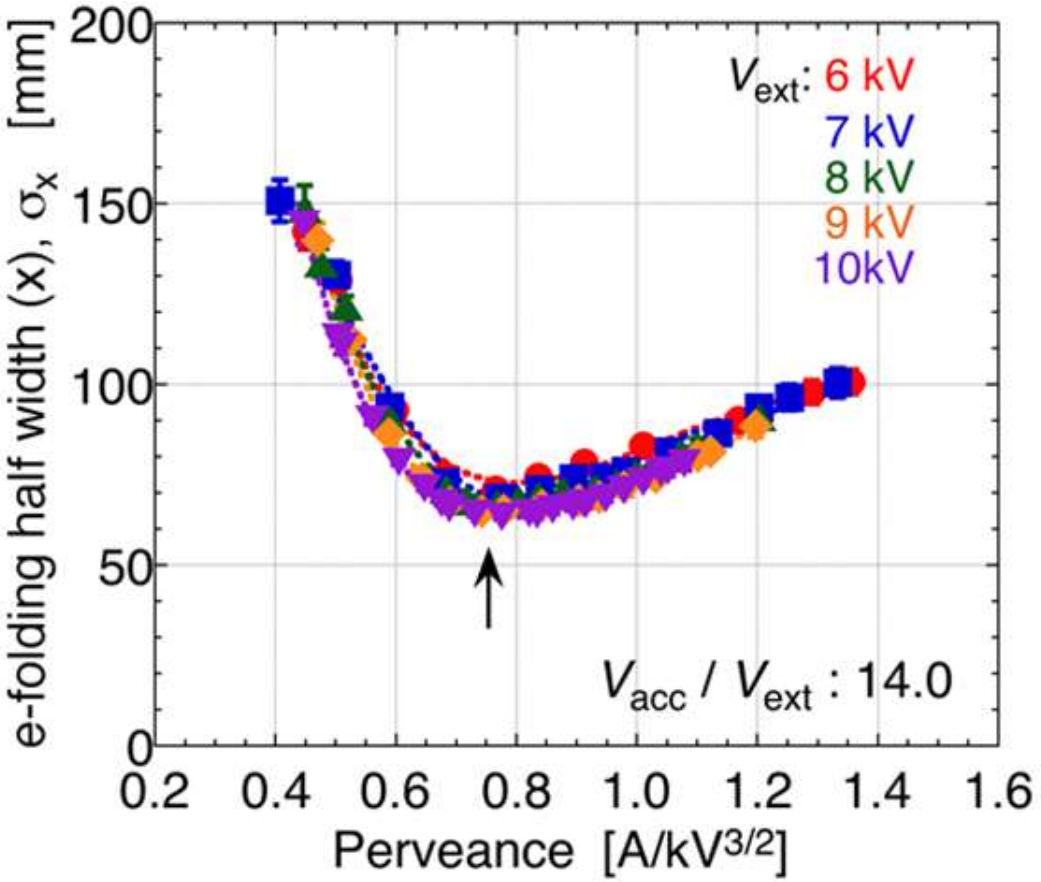
How is it for negative ion extraction?

Negative ion extraction

For negative ion extraction

- No established model even for electron extraction.
- Similar scaling has been obtained with positive ion extraction
  => perveance dependence looks identical
- Therefore, the meniscus formation similar with the case of positive ion extraction is usually assumed.

Is the meniscus formation really identical?



Meniscus formation mechanism

The plasma conditions are different between positive and negative beam extraction,

=>homogeneity/production, magnetic field/magnetization, species,,

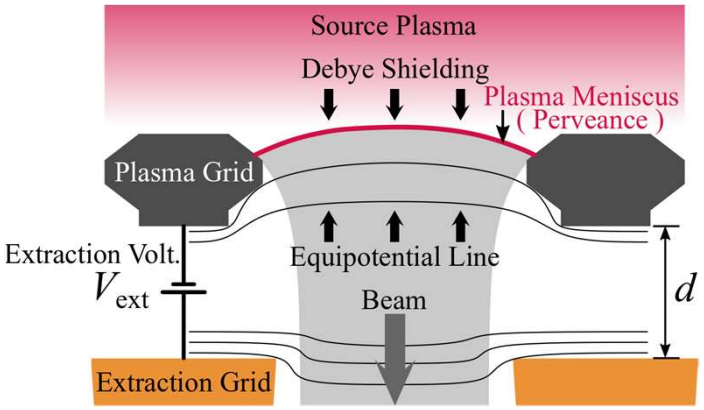
The identical mechanism of meniscus formation is NOT guaranteed

In this talk, recent experimental observations different from positive ion beam characteristics are reviewed;

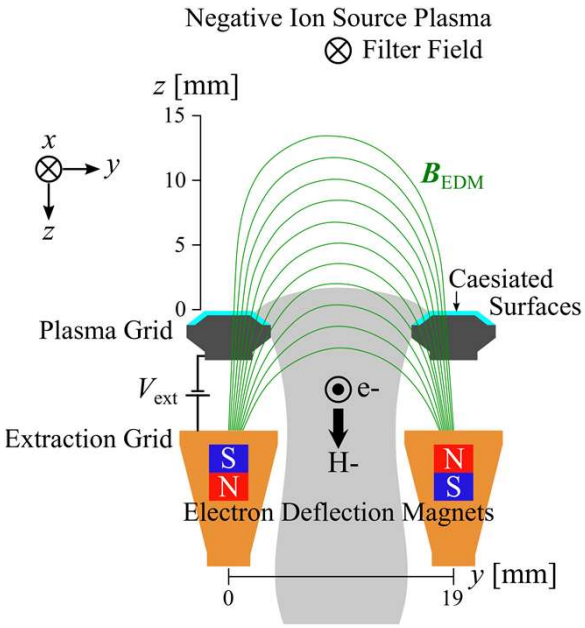
- ***Electron contribution***
- ***Response to external perturbation***
- ***Phase space structure***

The meniscus characteristics are discussed based on the experimental observations.

Positive ion meniscus



Negative ion meniscus



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Contribution of electrons

For the positive ion meniscus, electrons are considered to play a role through ***Debye shielding*** and ***Bohm criterion***

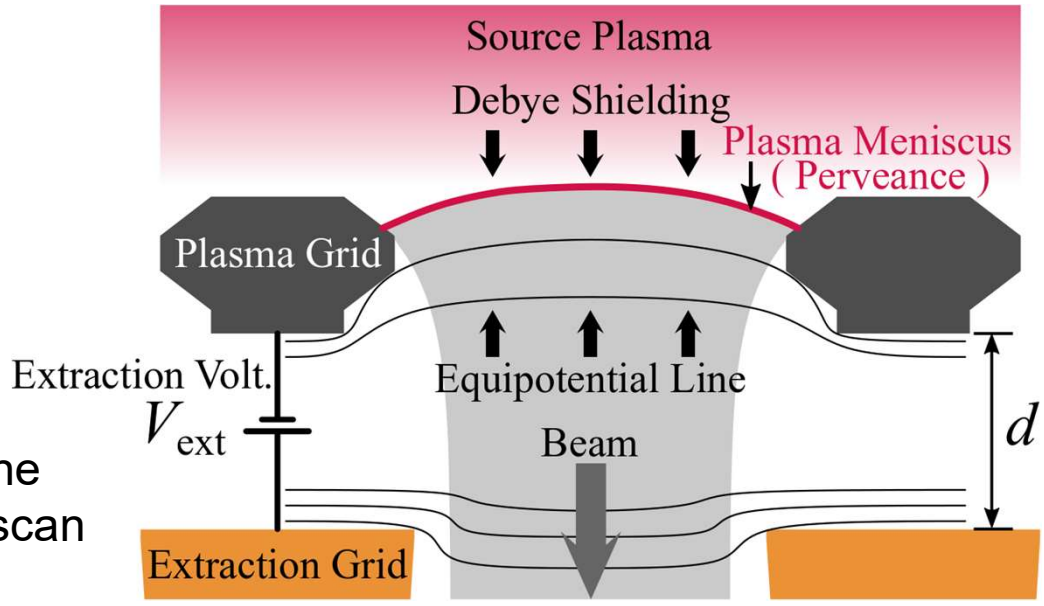
Debye shielding

$$\lambda_D = \sqrt{\frac{k_B T_e}{\varepsilon_0 n_e}}$$

Bohm criterion

$$C_s = \sqrt{\frac{k_B T_e}{m_i}}$$

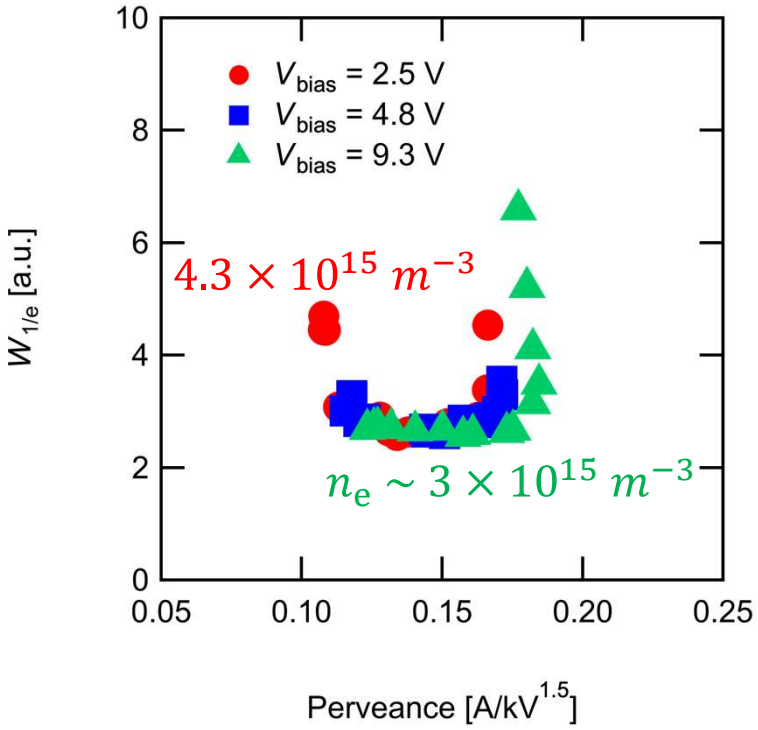
Positive ion meniscus



In order to investigate the electron contribution to the negative ion meniscus formation, the bias voltage scan was performed.

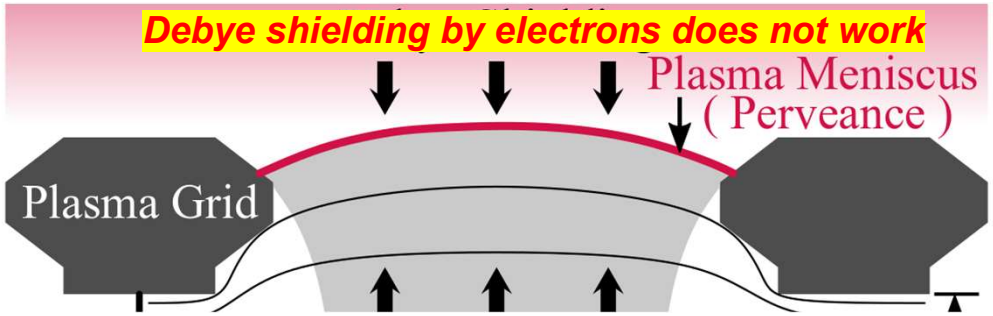
Contribution of electrons

M. Kisaki+ NIBS 2020 P2



The electron contribution to negative-ion meniscus formation is not identified
=> Effect of magnetic field ?

The negative ion meniscus is mainly determined by unmagnetized ions!
=> positive ions? or negative ions?



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Potential Perturbation to Positive Ion Source Plasma

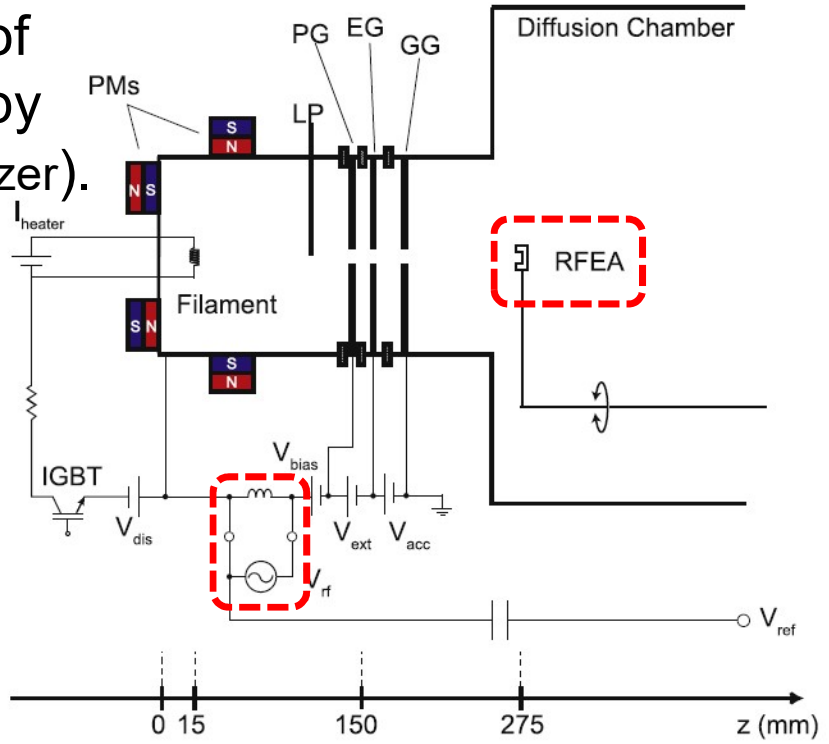
K. Takahashi+ New J. Phys.2019

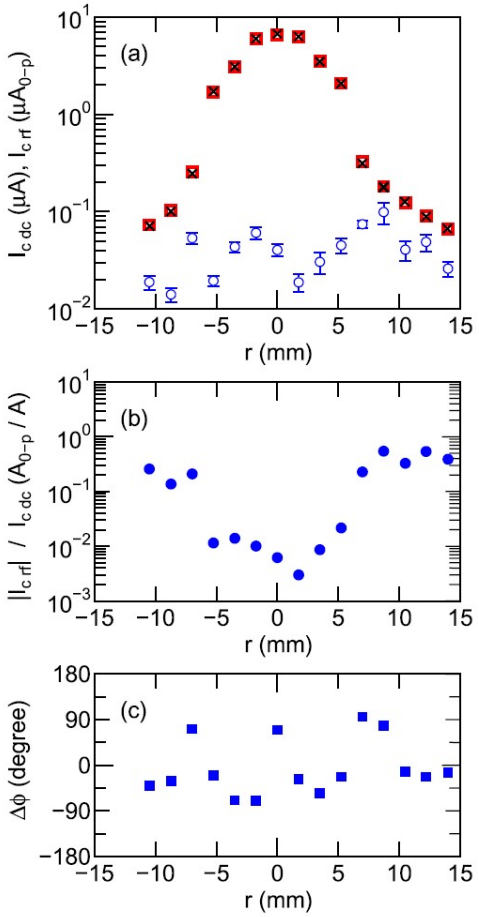
The rf voltage is superimposed on dc bias voltage as an external perturbation, and the response of the beamlet profile is observed by a RFEA (retarding field energy analyzer).

$V_{\mathrm{rf}} \sim 7.5\ V$

$T_{\mathrm{e}} \sim 3 - 4\ eV$

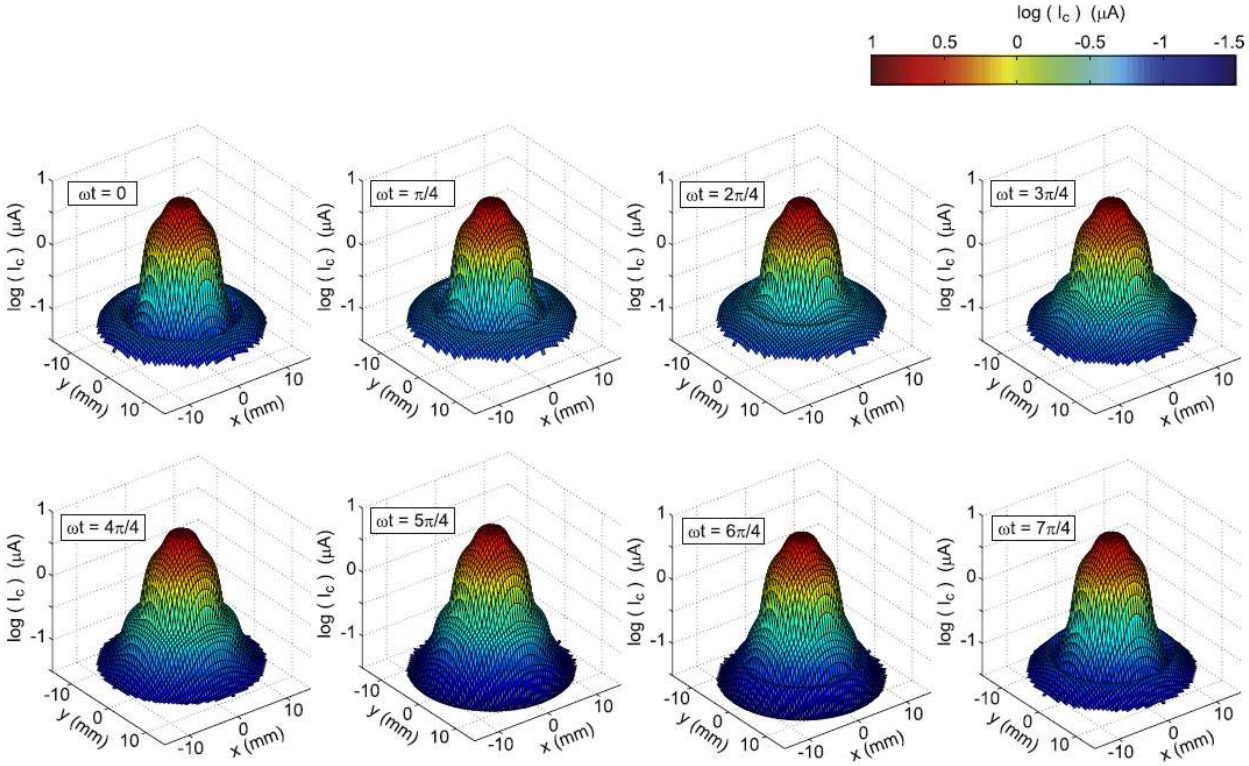
The beamlet profile responded to the applied rf.





Potential Perturbation to Positive Ion Source Plasma

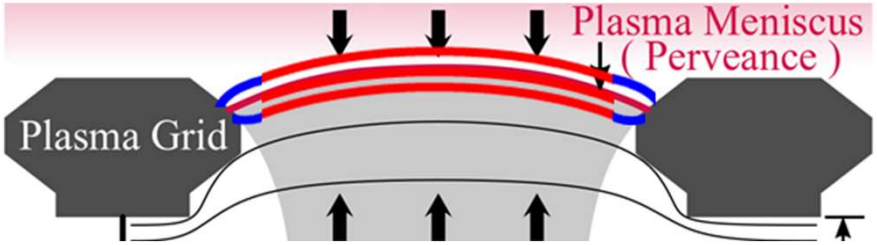
K. Takahashi+ New J. Phys.2019



The clear response can be only seen in the periphery.
=> No significant effect in the core

Response of positive ion meniscus is considered as

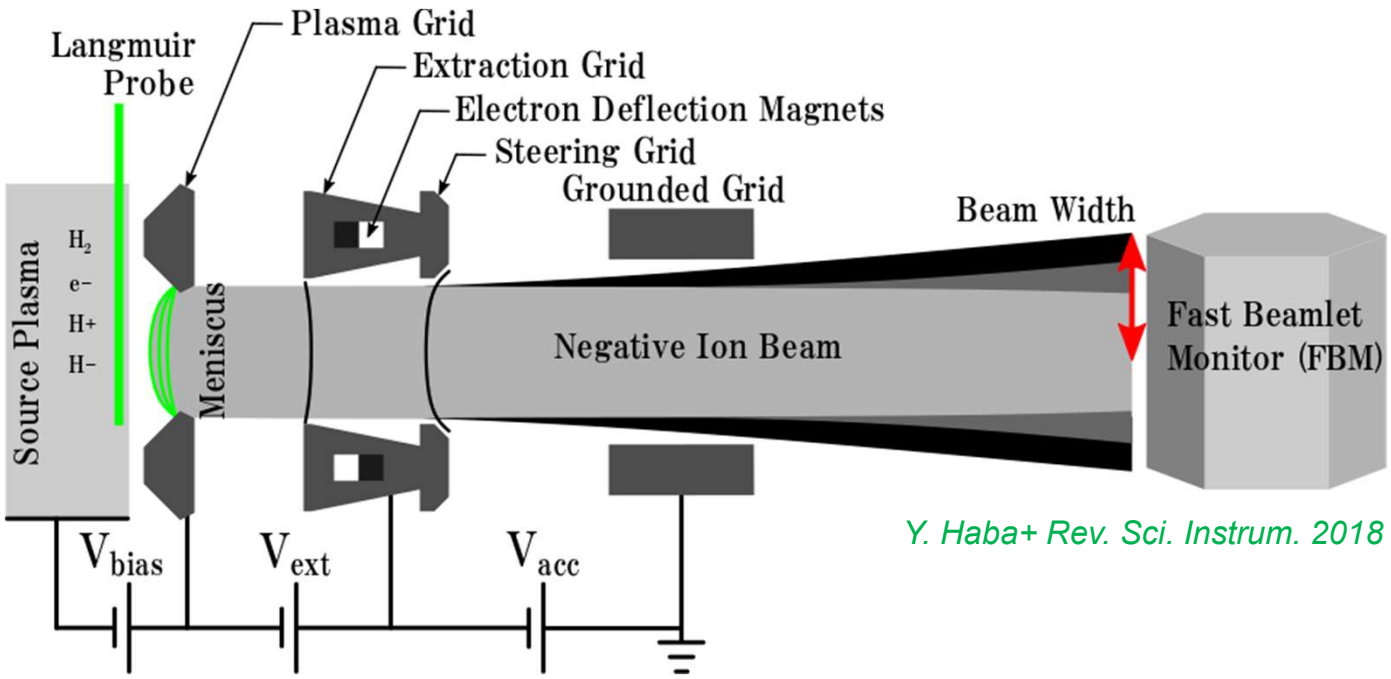
Robust meniscus in the core *and* ***relatively large deviation in the edge***



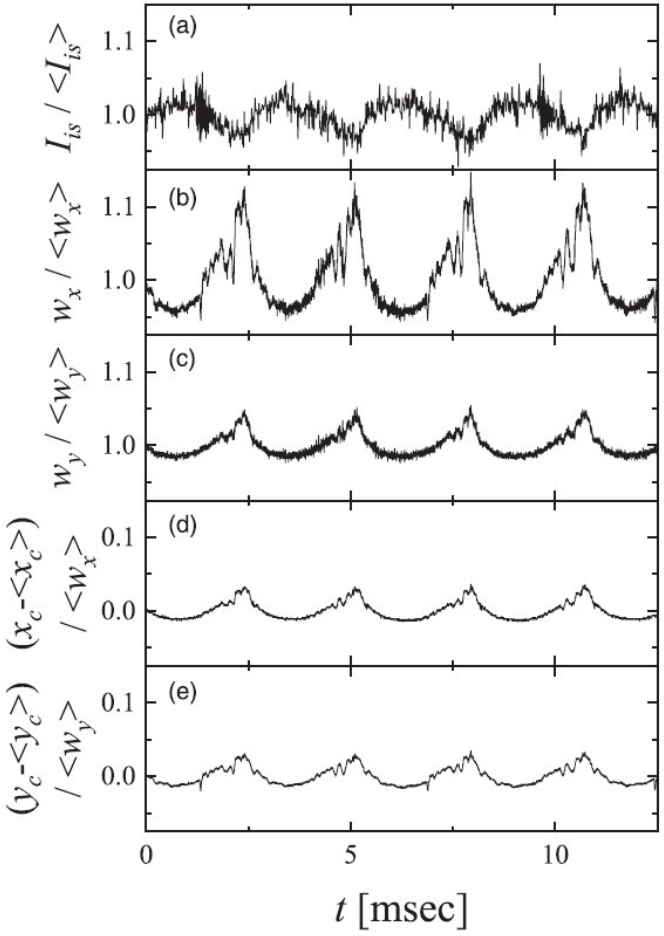
Potential Perturbation to Negative Ion Source Plasma

Y. Haba+ Jpn J. Appl. Phys. 2020

The beamlet response to the source plasma oscillation caused by bias voltage was investigated in the negative ion source (NIFS-NBTS).

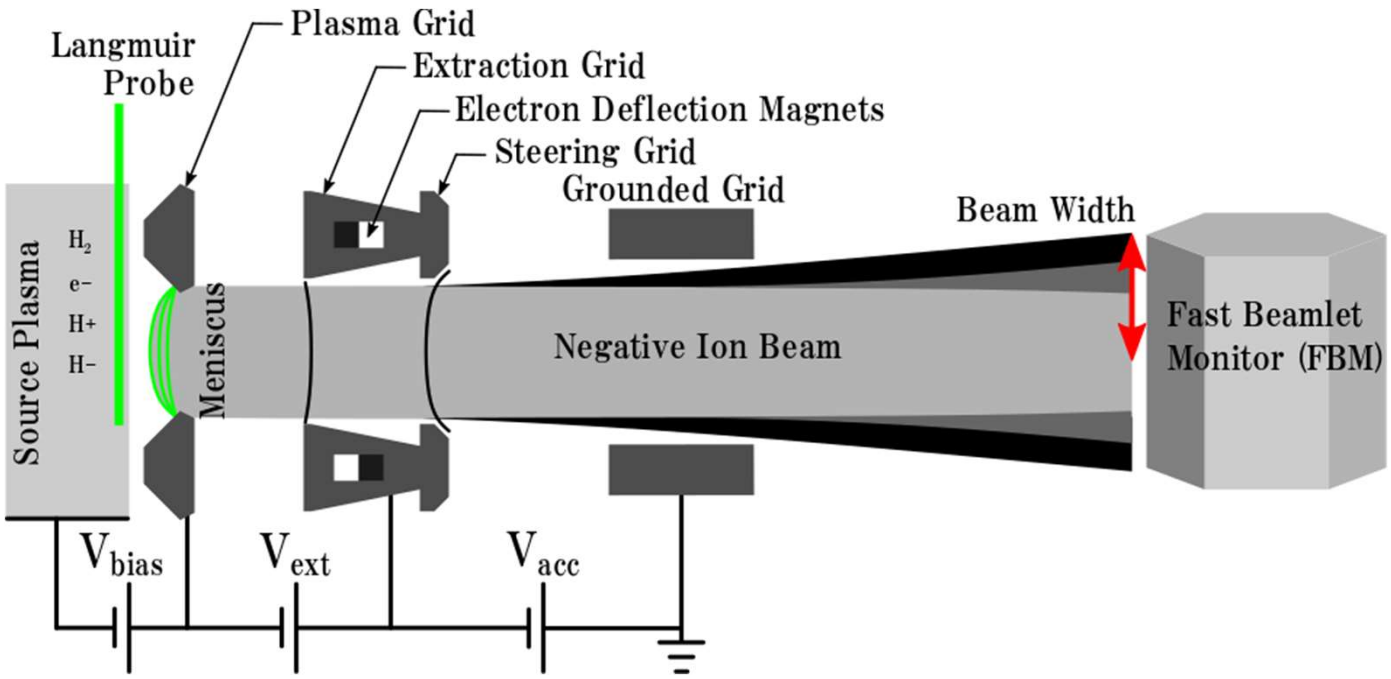


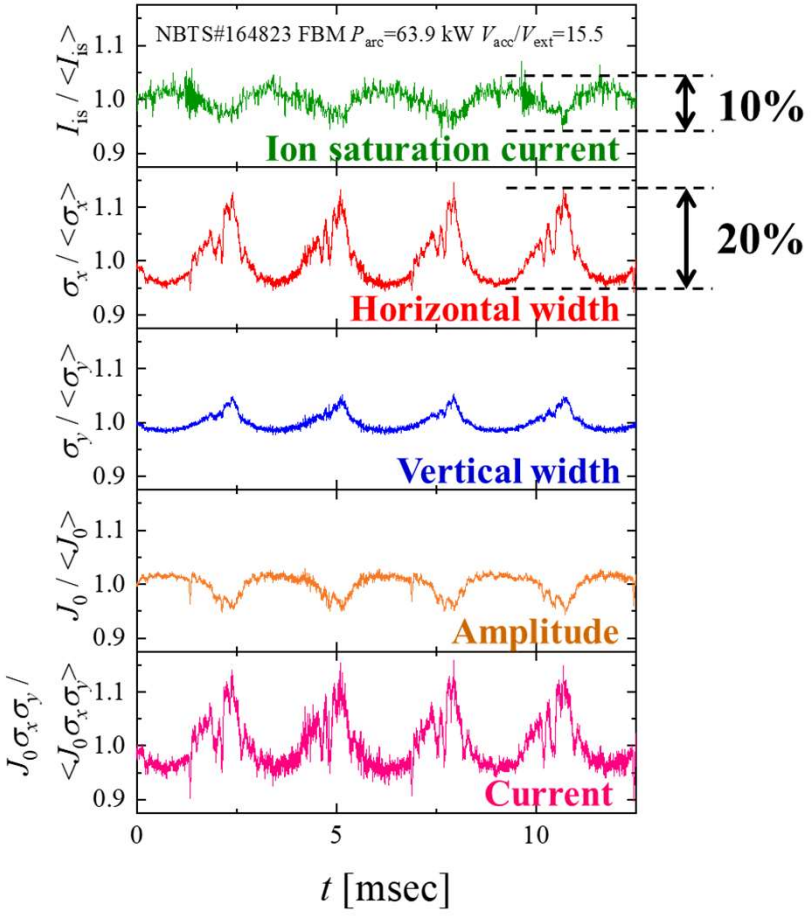
Y. Haba+ Rev. Sci. Instrum. 2018



Potential Perturbation to Negative Ion Source Plasma

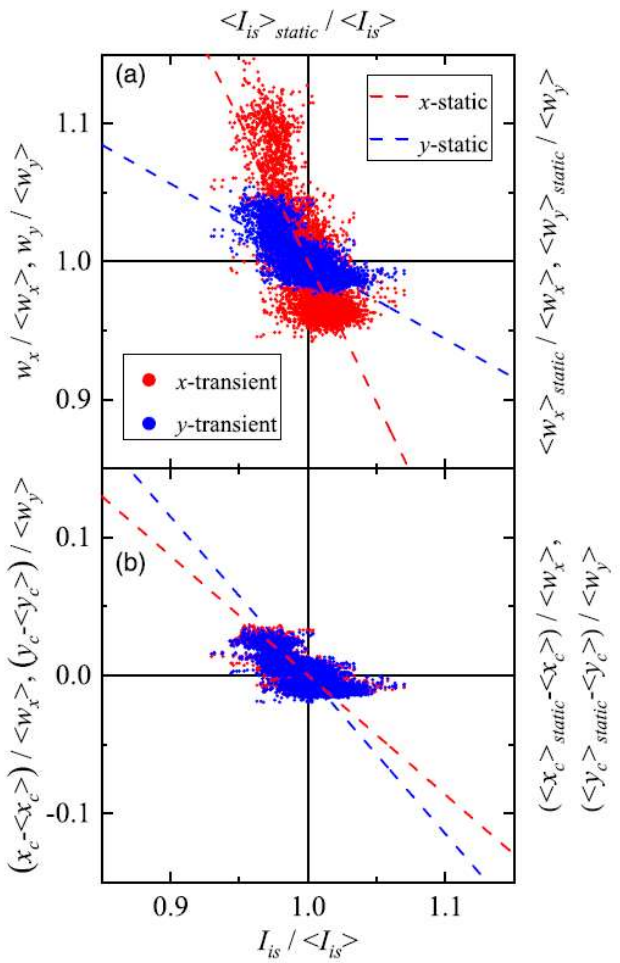
Y. Haba+ Jpn J. Appl. Phys. 2020





Potential Perturbation to Negative Ion Source Plasma

Y. Haba+ Jpn J. Appl. Phys. 2020



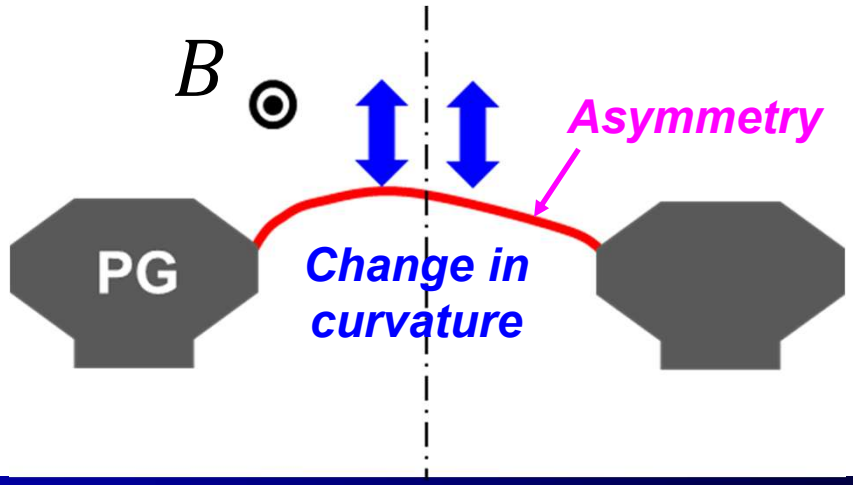
The beamlet width responds

=> meniscus curvature changes near the axis changes

=> different robustness from positive ion meniscus

The beamlet axis position responds

=> asymmetry of meniscus shape near the axis



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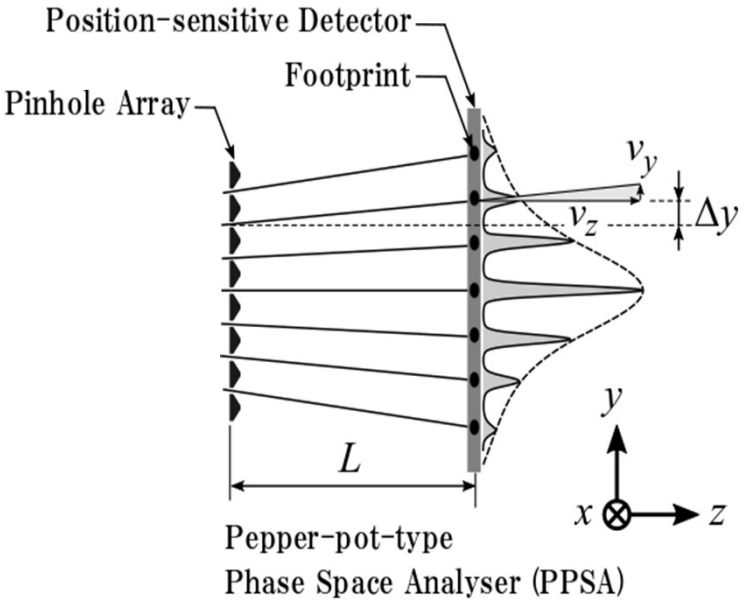
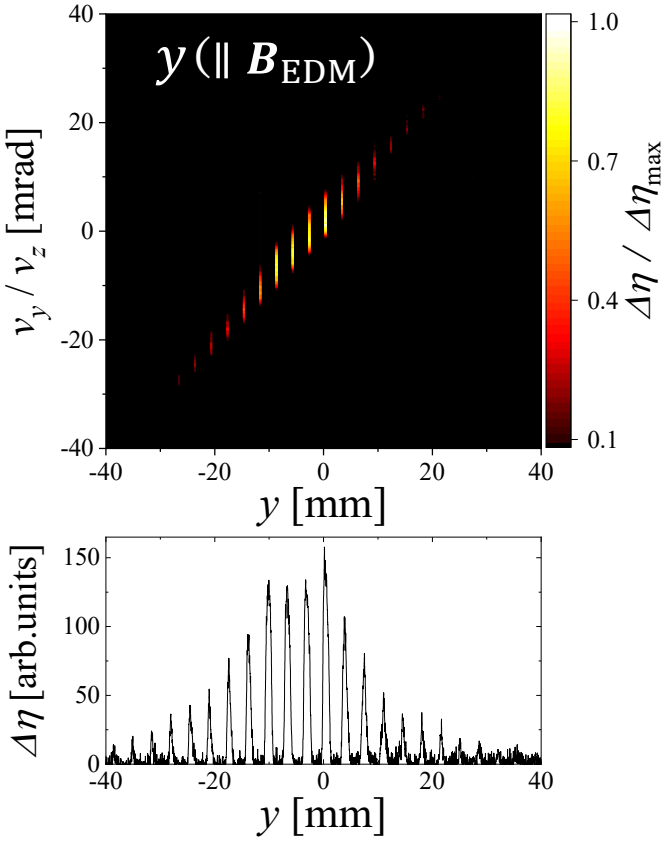
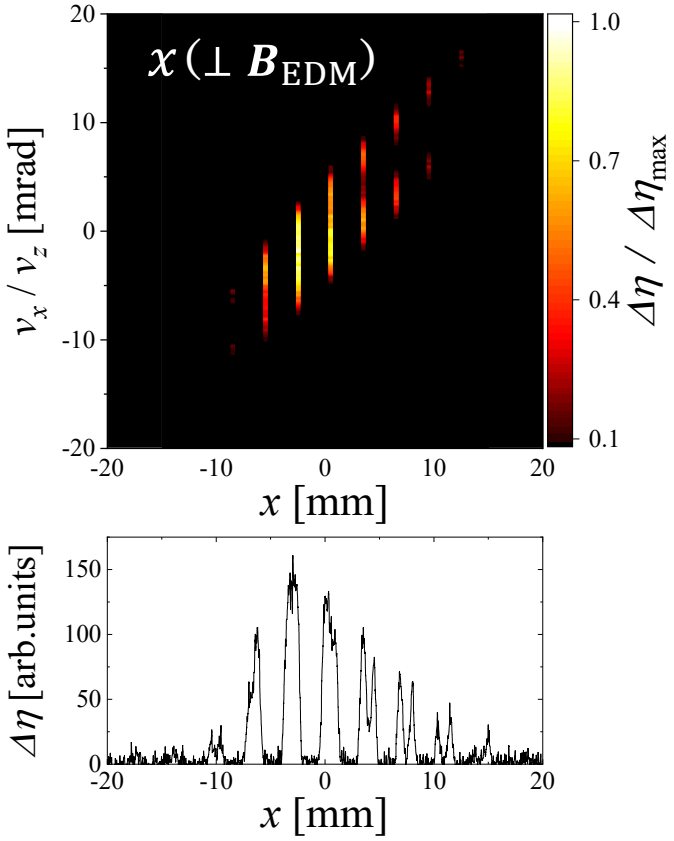
Phase Space Structure

Y. Haba+ New J. Phys. 2020

The phase space structure of negative ion beamlet was investigated, and the different structures were observed between vertical and horizontal directions.







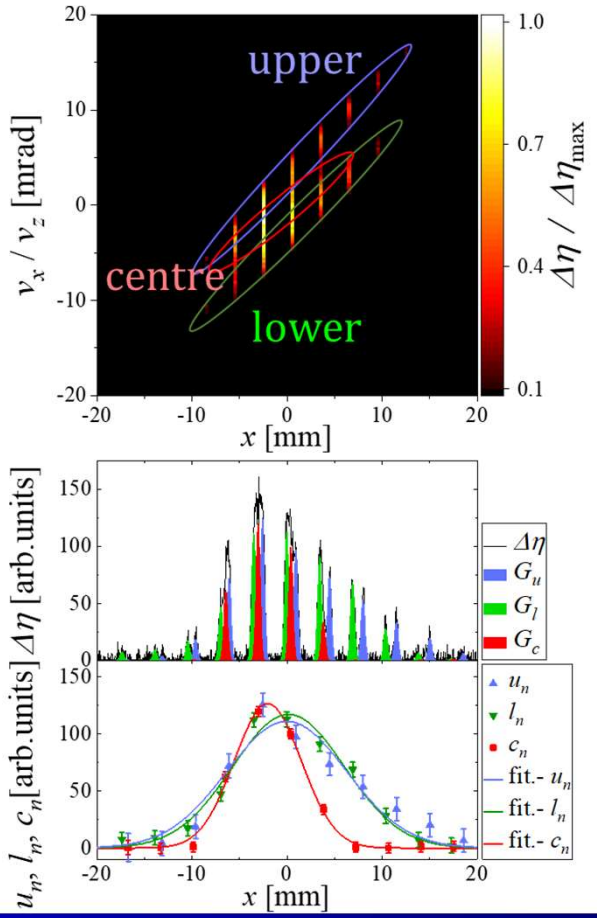
Phase Space Structure

In y direction,
the single Gaussian beam was identified

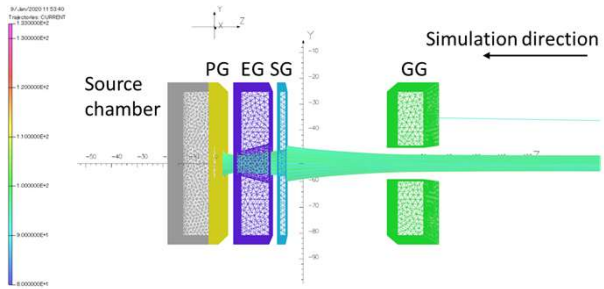
In x direction,
the three components of Gaussian beam were identified

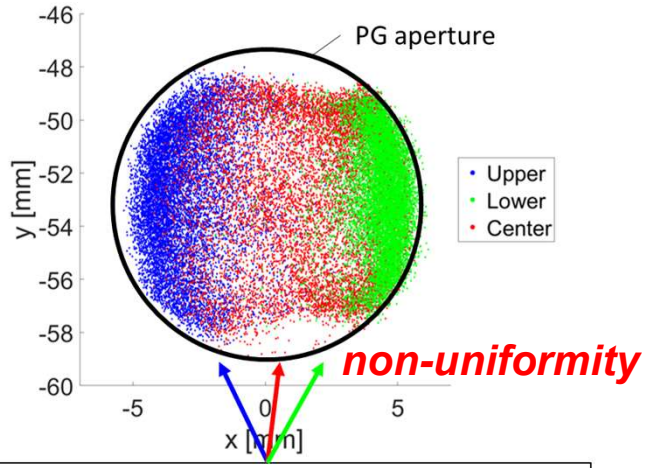
The inversely calculated beam trajectory revealed **the three components come from three different locations at meniscus**. **The non-uniformity of negative ion current density at the meniscus** was also indicated.

Y. Haba+ New J. Phys. 2020



J.Slief + NIBS2020





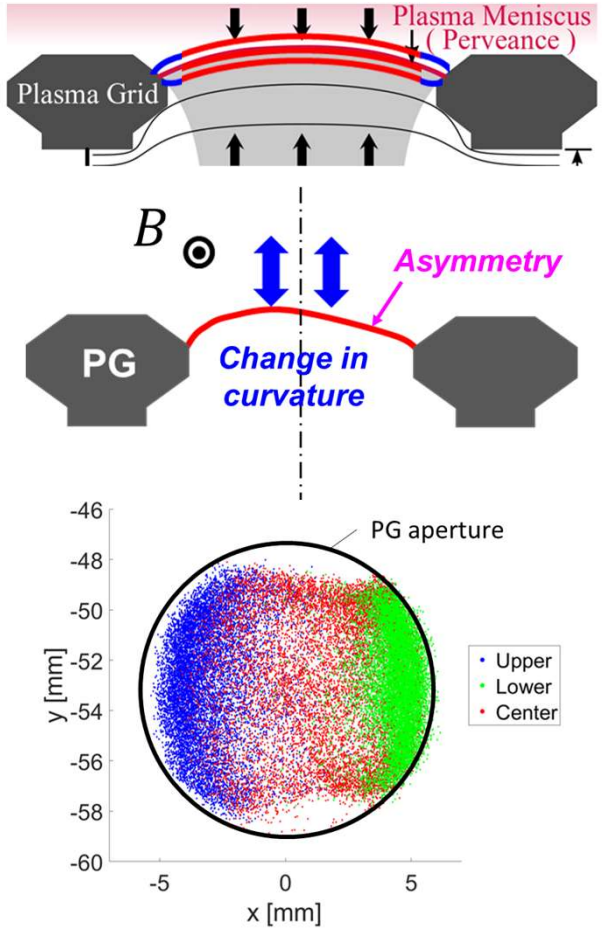
Confirmed: different components, different locations

Summary

Recent experiments showed that the negative ion meniscus forms in the different way from positive ion meniscus.

	El. contribution	Meniscus neat the axis	uniformity
Positive ion meniscus	◎	Robust/constant curvature, symmetry	◎
Negative ion meniscus	×	Less robust/ change in curvature, Asymmetry	×
Remarks	Effects of magnetic field		Localized source

These physics pictures should be taken into account for modeling of negative ion meniscus



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